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Association of conductivity and geomagnetic activity in the plasma sheet of geomagnetotail

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Abstract : We have computed the specific conductivity σ of the plasma sheet for the selected 22 substorm events occurred in the maximum solar activity year and found out the variations of the above with plasma β-parameter (ratio of plasma pressure to magnetic pressure) and geomagnetic activity indices The dependence of the correlation coefficient R_m between planetary index K_p and sunspot number χ on the specific conductivity of the plasma sheet was studied The effect of storm index D_{st} on specific conductivity was found that as the D_{st} level increases, specific conductivity falls and this reveals an anti correlation between the storm index and the geomagnetic activity in the plasma sheet

Keywords : Plasma sheet, specific conductivity, geomagnetic activity

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1. Introduction

The plasma sheet in the geomagnetotail is the site of the dynamo that drives auroral currents, which in turn produces geomagnetic variations measured by the auroral electrojet indices [1]. The energy for the dynamo is provided by the solar wind generated Poynting flux through the lobe. The poynting flux is absorbed in the plasma sheet and transformed into mechanical or thermal energy through dynamic and thermodynamic processes respectively. This energy is partially precipitated into the ionosphere and partially injected into the ring current. The Poynting flux through the lobe consists of two parts : one is related to convection fields, and the other to fast mode waves propagating through the lobe. The rates at which these forms of energy flux are absorbed depend on different characteristics of the plasma sheet [2]. The convective poynting flux from the lobe can exist only if there is an earthward convection in the plasma sheet, *i.e.*, the rate at which it is absorbed. Because it crosses the separatrix between open lobe and closed field lines, its existence requires an electric field on the separatrix and thus involves magnetic reconnection [3]. Enhanced absorption requires enhanced reconnection and conduction in the plasma sheet.

The rate at which the energy flux absorbed in the plasma sheet depends on its temperature and the thickness of the plasma sheet boundary layer. The auroral electrojet index *AE* correlates well with the temperature of the plasma sheet [4]. This correlation suggests that thermodynamics of the plasma sheet is important as well as its dynamics. The present paper incorporates the thermodynamics and geomagnetic activity in the plasma sheet.

2. Data

Geomagnetic and solar activity indices have been used to study the dependence between plasma sheet parameters and geomagnetic activity.

1. The plasma β-parameter and plasma sheet temperature T for the 22 isolated substorm events occurred in the maximum solar activity years (1978 and 1979) from the GEOS-2 observations have been collected [5].
2. *AE*, D_{st} and sunspot numbers correspond to the selected substorm events.

The *AE* index was derived from the horizontal component of the geomagnetic variations observed in the 10–13 observatories along the auroral zone in the northern hemisphere and was supplied by the World Data Centre C_2 for geomagnetism. The equatorial D_{st} indices and sunspot numbers were taken from the IAGA Bulletin and NSSDC Interplanetary medium data book, respectively.

The relationship between solar and geomagnetic activity was reported and was shown that the variation of solar plasma through the sunspot cycle changes the size of the magnetosphere and its interaction with the magnetosphere varies with the effectiveness of feeding solar plasma into the magnetosphere [6].

We have selected 22 substorm events from the maximum solar activity years 1978 and 1979, since during solar maximum the energy input into the magnetosphere is maximum. So it will be an apt period to study the magnetospheric phenomena like substorms and hence plasma sheet behaviour.

3. Method

(a) Plasma sheet heating :

Consider the perturbation displacement of a particle in the z-direction through the plasma sheet along a closed field line with antisunward propagating ULF waves having wave vector k with components (k_x, k_y, k_z) and frequency ω. The ULF waves perturb a field line with a parallel wave number $k_{\|}$ and excite oscillations of this field line at its own resonance frequency ω_A. If $\omega = \omega_A$, oscillations will grow to a very high amplitude and a resonance layer develops between the lobe and neutral sheet

The energy dissipation rate Q integrated over the resonance layer and the wave temperature T_w are given by [7] as

$$Q = 4\pi^2 \Delta z P_{f:} / \mu_0 \left[(T/T_w - 1)^2 + \pi^2 k^2 \Delta z^2 \right] \quad (1)$$

and

$$T_w = 1/2 m_i \left(\omega^2/k_{\parallel}^2\right)\left[(k_{\perp}/k)/(1+2/\beta)\right], \quad (2)$$

where T is the temperature of the plasma sheet; $P_{f:}$ is related to the amplitude of magnetic fluctuations in the lobe ~10^{-4} – 10^{-2} nT^2 Hz [8], Δz is the scale length of the gradient of the Alfven speed in the resonance layer where the absorption of ULF waves occur and m_i and β are the average ion mass and plasma β-parameter in the plasma sheet, respectively

As the heating rate of the plasma sheet is never zero, a steady state of the plasma temperature can be reached only when the length of the plasma sheet is balanced by the loss through convection or through heat conduction into the ionosphere. So the heating rate has a maximum value at $T = T_w$.

Eq. (1) indicates the possibility of chaos When a parcel of plasma convects through the heating layer, the amount of heating is determined by the temperature of the plasma sheet. Once the plasma parcel has traversed, the temperature of the heating layer increases ($T < T_w$) or decreases ($T > T_w$). Thus the next parcel of plasma will be heated by different amount After one more traversal, the plasma sheet temperature changes again and the heating rate also changes and so on.

(v) Conductivity in the plasma sheet :

The physics of the entropy change described by Ref. [7], invokes the heating mechanism of the thermal catastrophe model of substorms. This model was developed specifically in response to the observation that the plasma sheet temperature is positively correlated with AE magnitude. Under appropriate conditions, Alfvén waves are absorbed in the resonance layer near the edge of the plasma sheet. This gives rise to a stepwise increase in thermal energy within the layer The Poynting flux entering the plasma sheet is of the order of 10^{17} – 10^{18} erg cm^{-2} s^{-1}, and the degree and duration of heating process then depends on the conduction speeds within the plasma sheet This model has the advantage of allowing the resonance layer to be extended in the x-direction, thus permitting the energization at several locations, while being restricted in the z-direction. The study on the conductivity in the plasma sheet will give the main aspects of substorm energy dissipation comparable with the ionosphere.

In Sweet-Parker's reconnection model [9], the velocity V with which the magnetic fields are diffusing into each other at the reconnection region is given by $V = 1/L\sigma$, where L is the half length of the current sheet and σ is the specific conductivity of the plasma sheet particles and was determined to be varying with plasma sheet temperature T as

$$\sigma = 2 \times 10^{-14} T^{3/2} \quad (3)$$

Using eqs. (1) and (2), the plasma sheet temperature T for the selected 22 substorm events were computed. For computing T, we used $\omega = 20$ kHz, $K_{\parallel} = k \cdot B/|B|$, $k_{\perp} = \sqrt{(k^2 - k_{\parallel}^2)}$,

Δz = 500 km and $P = 0.005$ nT^2 Hz and all other parameters used are as given in Ref. [10]. The σ values during the selected events were also calculated using the computed values of T and the variation of σ with plasma sheet parameters and geomagnetic activity was studied.

4. Results and discussions

Figure 1 represents the variation of σ with plasma β-parameter during the selected substorm events. From Figure 1, it is clear that as plasma β-parameter increases, σ also increases and reaches maximum at a particular value of β, and then begin to decrease. The wave temperature of the wave propagating through the resonance layer of the plasma sheet increases with the increase of plasma β-parameter and reaches maximum at a particular value of β, and then begins to decrease [11]. Due to the association of temperature and specific conductivity in the plasma sheet during geomagnetic activity, the nature of variation of specific conductivity resembles that of temperature with plasma β-parameter. The heating of the plasma in the plasma sheet is balanced by the loss through convection or through heat conduction into the ionosphere. The degree and duration of heating process in the plasma sheet depends on the convection speeds within the plasma sheet, which allows the convection of particles and energization of particles at different regions of the plasma sheet [12]. As plasma β-parameter increases, the convection or conduction rate also increases and the temperature and specific conductivity decreases and thus plasma sheet heating decreases.

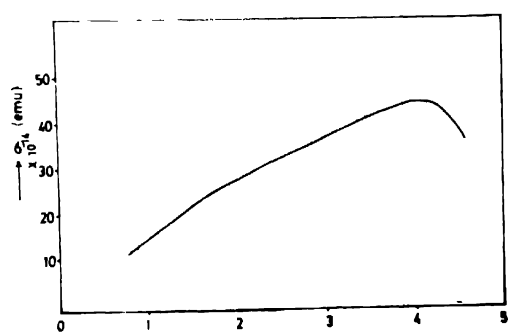

Figure 1. Variation of σ with plasma β-parameter.

Figure 2 is the graphical representation of the variation of specific conductivity σ in the plasma sheet with AE index. From Figure 2, we observe that as the auroral electrojet index increases, the specific conductivity also increases and reaches a maximum value (AE = 240 nT) followed by a decrease of higher values of AE. This effect can be explained as follows. The energy flux absorption in the plasma sheet depends on its temperature [12]. During high activity times, the temperature of the plasma sheet increases and hence the specific conductivity. As the specific conductivity increases, the rate of absorption increases and then reaches a maximum value at some critical temperature and then begins to decrease. Thus a thermal catastrophe can occur during which the plasma sheet specific conductivity increases rapidly.

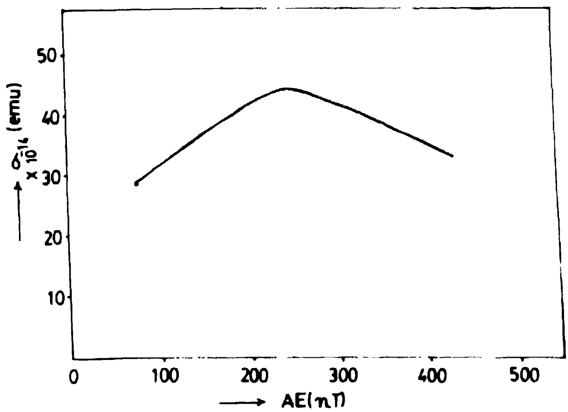

Figure 2. Variation of σ with AE index.

The study on the variation of the correlation coefficient R_m between the planetary index K_p and sunspot number χ with σ during the selected substorm events is shown in Figure 3. From Figure 3, we observe that the positive correlations are more prominent than negative correlations *i.e.* sunspot number and K_p index have great influence on plasma sheet thermodynamics. This study agrees well with that of [13] which reveals the correlation between plasma sheet parameters and sunspot number.

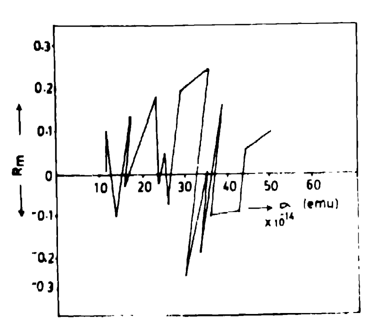

Figure 3. Variation of R_m with σ

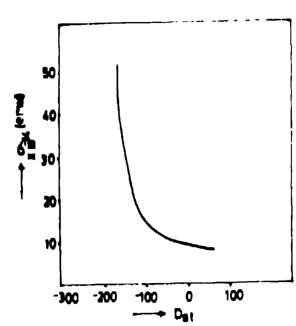

Figure 4. Variation of σ with D_{st} index

Earlier studies showed that solar activity has considerable effect on AE and D_{st} and which inturn affects the plasma sheet parameters. Here we checked the nature of variation of σ in the plasma sheet during substorm events with D_{st} index. Figure 4 reveals that as

D_{st} levels increase, the specific conductivity of the plasma sheet decreases. This may be due to the fact that when D_{st} level increases, the ring current intensity begins to grow and the energy input from the solar wind increases. Thus there is a decrease of temperature in the plasma sheet and so the specific conductivity.

5. Conclusion

Theoretical understanding of the production and absorption of energy in plasma and its conversion into random thermal motions is still in a primitive stage, partly because of its non-linear nature and partly due to the difficulty in disentangle heating effects from confinement effects in experiments. Particle diffusion in high temperature plasma lies at the heart of plasma confinement problems. The current work is an effort to study plasma heating processes which excite instabilities.

References

[1] D V Vassiliadis, A S Sharma, T E Eastman and D Papadopoulos *Geophys. Res. Lett*. **11** 1841 (1991)

[2] R A Smith, C K Goertz and W Grossmann *Geophys Res Lett*. **13** 1380 (1986)

[3] B G Harrold, C K Goertz, R A Smith and P J Hansen *J Geophys. Res* **95** 15039 (1990)

[4] C Y Huang, C K Goertz, L A Frank and G Rostoker *Geophys. Res Lett* **16** 563 (1989)

[5] Z Y Pu, A Korth and G Kremser *J Geophys. Res* **97** 19341 (1992)

[6] D Venkatesan, A E Ananth, H Graumann and Suresh Pillai *J. Geophys Res* **96** 9811 (1991)

[7] C K Goertz, R A Smith and L H Shan *Geophys Res Lett* **18** 1639 (1991)

[8] R A Smith, M L Goldstein, M R Sands, R P Lepping, C K Goertz, B G Harrold, C A Fitch and L H Shan *Geophys Res Lett* **17** 1845 (1990)

[9] S I Akasofu *Physics of Magnetospheric Substorms* ed S I Akasofu (Holland D Reidel) p 55 (1977)

[10] P R Prince, S Bindu, G Renuka, M S Sindhu and C Venugopal *Proc of the 9th Kerala Science Congress* ed P K Iyengar p 315 (1997)

[11] S Bindu, G Renuka, M S Sindhu and C Venugopal *Indian J. Phys*. **68B** 443 (1994)

[12] C K Goertz and R A Smith *J Geophys Res*. **94** 6581 (1989)

[13] S Bindu, G Renuka and C Venugopal *Indian J. Radio & Space Phys* **24** 50 (1995)